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PROPOSAL TO NATIONAL ACCELERATOR LABORATORY FOR A SEARCH FOR MAGNETIC MONOPOLES

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ABSTRACT: The fundamental particle whose discovery would require the most thorough reassessment of modern physics is the magnetic monopole. A beam of 500 Gev protons in principle makes possible the creation of pairs of monopoles each of mass up to 15 m_p (p = proton) under controlled laboratory conditions. We propose to use solid state track detectors to observe directly the flight of monopoles which hopefully would be created by interactions in a target foil placed directly in the accelerator beam. The method has the merits of simplicity and directness, the use of detectors with zero background, applicability within the entire mass range opened by increased accelerator energies, and applicability within the entire charge range regarded as plausible in the light of past and current theoretical work. The experiment could be run as a satellite to another experiment or to the early tune up of the accelerator.

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II. INTRODUCTION

A clear demonstration of the existence of magnetic monopoles[1] would lead to profound changes in modern physics. First, the presence of monopoles would restore symmetry to Maxwell's equations, which include an electric charge e but no analogous magnetic charge or pole strength g. Secondly, as was also suggested by Dirac,[1] quantization of the electric charge would arise naturally from the existence of a magnetic charge, since Dirac's quantum mechanics requires that

$$eg = nhc/4\pi, \tag{1}$$

where n = an integer, h = Planck's constant, and c = velocity of light, so that if both e and g exist, each must have a smallest value. In addition, if monopoles exist, the electromagnetic field will lack some of the symmetry properties commonly ascribed to it -- losing its invariance with respect to time reversal and space inversion.[2]

Recently, Schwinger has suggested that the existence of unpaired magnetic poles as <u>dyons</u>, particles having both electrical and magnetic charge, would answer the origin of the bewildering array of "elementary" particles and their groupings.[3] They could also explain the observed weak violation of CP symmetry. Since such particles would be observed in virtually all experiments designed to detect purely magnetic particles, we can readily include them in our discussion of monopole searches. The values of n in eq (1) above from Schwinger's theory would be 4 and 8 for different dyons.

In the past, experiments have been designed primarily to observe monopoles where the quantum number n is unity, corresponding to the lowest magnetic charge given by Dirac[1]; and, as a result, in most of the previous work poles of much higher charges would not have been detected, in contrast to what we propose here. In an earlier examination of equation (1), Schwinger[4] concluded that n is 4 (two separate factors of 2 being included); and as Carithers et al.[2] pointed out, n is at least 3 if quarks exist, since e would be replaced by 1/3e. A proposal by Schiff[5] would eliminate this factor of 3, but it in turn has been criticized by Peres.[6] At any rate, values of n = 1, 2, 3, 4, 6, 8, and 12 are by no means unlikely, depending on whether quarks exist and on whether none, one, or both of Schwinger's factors of two are appropriate or upon whether dyons exist.

a. Monopole Properties

The known, rigorously calculable properties of monopoles stem from the magnetic charges given by eq (1). A detailed survey of calculated properties is inappropriate here, but three properties that will be referred to here are these: (1) By analogy to an electrical charge's attraction to a dielectric material, a magnetic charge is magnetostatically tightly bound to ferromagnetic[7] or paramagnetic[8] matter, and can therefore be stored for considerable periods of time, a useful property for searches for monopoles stored in nature. (2) A magnetic field accelerates a monopole with a force gH, so that it gains energy at a rate of roughly 20n MeV/kilo-gauss-cm. In moving an atom distance in a 100 kG field, a monopole thus gains a minimum of 45 eV -- more than the energy needed to displace an atom from its lattice site -- and can therefore be removed from matter under suitable conditions.[9] (3) Fast-moving monopoles are heavily ionizing particles -- equivalent in their ionization to relativistic atomic nuclei of atomic number $68.5n^2$ (an energy loss of 8 n^2 GeV/g/cm^2 of matter traversed).[10] This property allows us to understand the slowing down of monopoles and to specify appropriate detection methods. There is no direct theory of what the monopole mass should be.

b. Hypotheses of Monopole Experiments

Monopole experiments including the present experiment are usually built around the assumption that sufficiently high energy interactions of particles with matter would produce monopole pairs, which are either directly observed in flight or slowed down and later accelerated into a detector system. This general hypothesis has many variants.

1. Accelerator searches are the most direct of those involving interactions. Particles of known energy and trajectory

are fired at a target. The particles created in the resulting nuclear interactions have in some cases been looked for by placing detectors downstream next to the beam[11] or in other cases placing a thermalizing and/or trapping medium downstream[9, 12-14] A magnetic field is then used to guide monopoles and to accelerate them into detectors that are well removed from interference generated by the particle beam. A summary of the results of such experiments is given in Table I. This table indicates that extremely low cross sections ($< 10^{-40}$ cm^2) have been set for monopole production, but that the available energies of accelerator particles limit the monopole mass (in terms of the proton mass m_p) to $< 3m_p$. If the true mass were greater than 3 m_p, the accelerators used so far could not have produced a monopole pair, with the exception of the first results from the I.P.H.E. machine at Serpukhov[15], which extends to 5 m_p.

Similarly, the charge region to which the cross section limits apply has been limited by the detection systems. The limits are good for $n = 1$, $n = 2$, and in some cases possibly for $n = 3$, but surely not for the higher values $n = 4$, 6, 8, or 12 that might obtain if quarks exist[2] and if Schwinger's ideas apply.[3,4]

2. Searches for monopoles in nature are the other possible route to finding monopoles. Most of the studies in this category have attempted to utilize the particle energies of the cosmic radiation, which extend nearly ten orders of magnitude above those

which have been used in accelerator studies.[16] It is not our purpose to review these studies in detail. We merely note that the most restrictive limits were set by us in a series of studies[8,17,18] and have recently been roughly equaled over a portion of the mass range by Alverez _et al_[19]. The status of such searchès was briefly reviewed[20] recently. Although these searches have been extended to higher masses than will be available from 500 GeV proton collisions, the accelerator experiment has the virtue of directness and can place more stringent limits on production cross sections.

III. THE EXPERIMENT

We propose to place solid state track detectors (mica, polycarbonate, and cellulose nitrate) downstream from a scattering foil or plate to observe directly in flight monopole pairs which are hopefully formed by interactions in the foil. By positioning the foil so that the beam passes through a bending magnet immediately after interacting, the magnetic poles can be separated from the charged particles and the detectors accordingly placed so as to detect only monopoles. By the use of two sets of detectors, both north and south poles can be observed, providing an extra and useful check if heavily ionizing particles are seen. The precise experimental layout must await more detailed information on the accelerator facilities.

The proposed procedure depends on the unique properties of solid state track detectors: (1) insensitivity to lightly ionizing radiation and (2) detection thresholds which allow monopoles of any plausible pole strength ($n<1$ to $n>12$) to be detected by the two plastics listed and poles of $n \geq 2$ by the mica.[21,22] It is appropriate here to describe further the qualities of the detector system since the use of solid-state track detectors is relatively new to physics.[21-23] We have known since 1963 that in a wide range of dielectric solids heavily ionizing particles produce tracks which can be revealed by preferential chemical attack.[24] These etched tracks have been put to diverse uses[23] including the first identification of cosmic-ray nuclei more massive than iron.[25] This was accomplished by virtue of the fact that the background track density from lightly ionizing particles in the meteoritic detectors used was undetectably low.

The first space exposures of plastic detectors[26] helped establish that the detection threshold is determined by the primary ionization along the particle path[22] and subsequently led us to a new means of attaining high resolution of cosmic-ray particles utilizing the fact that the etching rate along a track is a function of the primary ionization.[27,28] From accelerator[27] and cosmic-ray[28] studies we now have reliable values of the relation between etching rate and ionization rate in Lexan polycarbonate and cellulose nitrate.

Happily, from a recent cosmic-ray study[29] we are fortunate to have a track from a relativistic nucleus of charge ≈ 69, which will allow us to view directly the sort of track we are seeking, and hence to establish that we would recognize it under specified scanning conditions.

We have calculated ranges in the Lexan detectors for poles of possible interest, including energy loss both by ionization and Bremsstrahlung calculated as described previously[8]. For the mass range ($5m_p$ to $15m_p$) and magnetic charge range ($n=1$ to 12) of interest the poles will have ranges great enough to give totally distinctive tracks, even at the initial operating energy of 100 to 200 GeV.

[The ranges extend from 85 microns for a $5m_p$, $n = 12$ pole produced by a 100 GeV interaction to 18 cm for a 15 m_p, $n = 1$ pole produced at 500 GeV.]

Cross sections measurable by this technique extend down to $\sim 10^{-42} cm^2$. For example for 15 m_p monopoles a one month run at 10^{13} protons/sec with a 10 mil aluminum foil would set a 95% confidence limit of 2.5×10^{-42} cm^2 for proton-nucleon collisions. Since the proposed experiment could be run as a satellite to other experiments, such a running time is not regarded as excessive.

IV. APPARATUS

All detector systems and appropriate holders will be supplied by the experimentors (GE).

It is expected that a bending magnet can be used that is either part of the NAL facility or part of another experiment to which ours could be parasitic. If not, it is likely that a suitable magnet could be borrowed from some other laboratory such as Argonne. If a 10 ft. long magnet of the design planned for the external proton beam is used, a magnetic field in the region of 100 gauss is adequate. The exact value depends on the mass and charge assumed for the monopoles and on the incident beam energy. The detectors would be along side the beam line downstream from the bending magnet in a drift space approximately 50 ft. long. Use of a shorter section of magnet operated with a higher field would make shorter drift distances possible.

If a vacuum chamber is used in the drift space, the detectors should be placed inside it. An eight-inch diam. pipe with an access port would be adequate. It is not necessary to shield the detectors from other particles which might be scattered from the target.

A measure of the integrated dose of protons incident on the target is necessary. It is anticipated that a satisfactory beam integrator might be part of the accelerator monitoring system. Secondary emission beam integrators of the type used in the external beam lines at the ZGS would monitor the beam satisfactorily and could simultaneously serve as the target for this experiment.

No on line computation is needed.

The entire setup could probably be fit into the beam transport line between the main ring and the experimental area before the experimental area is ready. Since a steady beam current is not required, the experiment could proceed during the early accelerator tune-up period when accelerator operation is intermittant. Useful information could be obtained as soon as a 100-GeV beam is extracted from the accelerator. Later on the experiment could be run as a satellite to another experiment.

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TABLE I

Accelerator Searches for Monopoles

Study by (Ref.)	Energy (GeV)	Number of Protons	Max. Monopole Mass* (Proton Masses)	Production Cross Sections Quoted by Authors (Confidence Limit)
Bradner & Isbell[13]	6.3	5×10^{12}	1.1	$2 \times 10^{-35} cm^2$
Amaldi et al.[11,12]	25-28	4.5×10^{15}	3.0	$6 \times 10^{-41} cm^2$ (95%)
Fidecaro et al.[14]	27.5	4.5×10^{14}	3.0	$10^{-39} cm^2$
Purcell et al.[9]	30	6×10^{15}	3.0	$1.4 \times 10^{-40} cm^2$ (86%)
Gurevich et al.[15]	70	---	5.0	1.5×10^{-41} (90%)

*Maximum detectable charge $\sim 3(\hbar c/2e)$ or less, except for Gurevich et al